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Distributional employment impacts of renewable and new energy–A case study of China

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ABSTRACT

The main goal of this paper is to argue for the necessity and significance of studying the distributional employment impacts of renewable and new energy development (RNE). Based on the comprehensive review of the methodology and conclusions of existing literatures, this paper builds up an extended input–output model to study RNE's distributional employment impacts on gender and personnel structure. The case study of China's power sector in this paper affirmed earlier doubts that RNE development will indeed aggravate the gender inequality problem and add to the level of mismatch between the structure of labor demand and supply, causing structural unemployment problems. The quantitative analysis in this paper outlined here implies that from 2011 to 2020 the development of RNE will bring about 7 million employment gains, but only 81.8% of which can be realized due to the mismatch problem. The study of China may alert other countries to be less-optimistic about RNE's employment impacts and reaffirm the need to carry out the distributional employment impacts analysis. This paper concludes with policy suggestions such as providing suitable training and equal promotion opportunities for women, offering courses and vocational trainings to RNE-related majors, in order to reduce the structural unemployment problem and further speed up the development of RNE.

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1. Introduction

The world has witnessed an unprecedented growth in renewable and new energy (RNE) during the past decade. The benefits of RNE are widely accepted [1]. Apart from lower greenhouse gas emissions, researchers also confirm that the development of RNE can bring about better environmental quality, enhanced energy security and a larger-scale of green investment [2–4]. In recent years, scholars have turned to exploring renewable and new energy's employment impacts, in order to further ensure its development won't generate unexpected social costs, especially under the pressure of high unemployment rates.

As summarized in previous articles [1,5,6], there are mainly two types of studies which focus on the employment impacts of RNE: (1) those that use largely spreadsheet-based analytical models ("bottom-up"); and (2) those that use a more complex input–output (I/O) model of the economy ("top-down"). Analytical models generally focus on the renewable energy sector alone and collect detailed employment data on its different operation phases (such as construction, installation, operation and maintenance); therefore they are better at analyzing employment changes within the renewable energy sector (i.e., direct employment impacts). I/O models are able to quantify the interdependencies between the renewable energy sector and other sectors in the economy; therefore they are better at analyzing the employment changes in other sectors brought about by renewable energy development (i.e., indirect employment impacts). Although it is believed that in total, renewable energy development will bring net job gains to itself and to other sectors in the economy [5,7], it remains unclear how these total gains in employment are distributed among different job classifications, specialized levels (skilled/unskilled, low/medium/high, or the corresponding educational levels), territorial (local/foreign) or temporary natures (stable or temporary) and even genders (i.e., the distributional employment impacts) [8,9]. To some extent, the assessment of distributional employment impacts (DEI) is even more important than the judgment of the overall employment impacts, because it can testify whether those job gains are comparable to the current personnel structure and educational system, as well as whether they might add to the gender inequality problem. If those "job gains" are proven to be unsupported by the current labor market, they can only be called unrealistic and unattainable "job gains", and the reality might turn out to be just the opposite –net job losses. Therefore, to prevent a completely erroneous judgment about employment impacts, it is critical to carry out the employment impacts assessment from a distributional perspective.

Compared to the total employment impact assessment, there are much less literatures focusing on the DEI, something discussed in Section 2 of this paper. In fact, the various definitions of the distributional impacts (such as level of specialization, territorial and temporal natures, and gender) have added to the difficulties in understanding the DEI issue. As for the methods employed by these studies, it is found that the majority of them have employed analytical methods. However, the bottom-up perspective of analytical models brings two inherent problems. First, analytical models usually rely on questionnaires for their data sources. It is quite possible, for example, that one job is considered as a skilled job in one questionnaire but not in another; it is also possible that in one questionnaire, a job is counted simultaneously as both a manufacturing and a construction job. Therefore, it is very hard to ensure that all the data collected has a unified understanding of the distributional impacts; it is also hard to prevent the occurrence of duplication and omission. Second, the DEI analysis should aim to warn policy makers about the broad-scale structural unemployment problem. The significance of the analysis would be much greater if the warning is given at an economy-wide scale, rather than at the RNE sector alone. In all, these two problems have jeopardized the preciseness and significance of the results from analytical models. On the other hand, I/O models which reveal the economy-wide DEI based on macro-economic top-down data can overcome the aforementioned problems. However the biggest challenge for I/O models is the difficulty of obtaining distributional employment data for all sectors in the economy. Usually only a large-scale social survey can meet such kind of data needs. This is why there are, up to this point, very few DEI analysis based on I/O models.

Fortunately, China completed a national-scale demographic census at the end of 2010 [10] which provides just the right database for the economy-wide DEI. Therefore, this paper intends to focus on China's RNE development through 2020 and study the resulting DEI throughout the whole economy. Due to data availability constraints, only the RNE development in China's power sector is considered (RNE developments in other sectors are ignored).

Table 1 summarizes China's development goals in RNE in the power sector till 2020. This study is of great significance to China, and may also be helpful to other parts of the world. On the one hand, it develops the methodology and sorts out the data needed to measure the economy-wide DEI, which could give valuable reference to other studies. On the other hand, it helps China to avoid being blinded by illusory employment gains and gives her early warnings about the forthcoming structural unemployment problem. Ultimately this could allow the country time to adjust the current personnel and training system.

This paper is organized as follows. Section 2 gives a comprehensive review of the existing studies on renewable energy's DEI. Methodologies for studying the DEI of China's RNE development are introduced in Section 3. Results are displayed in Section 4. Finally, Section 5 draws further conclusions based on those results.

2. Review of the existing studies

Table 2 contains a list of studies reviewed, which have touched upon the DEI of RNE. For those studies employing analytical models, they have two main features. First, most of them [5,13,17] did not have a clear definition on DEI. Besides, there is a lack of systematic methodology to study DEI. Some just used a concept of "distributional factors" to break down the overall employment impacts. Only a few studies [6,18,19] had relatively clear definitions on DEI, but these detailed definitions differ in many ways. Second, even though researchers tend to classify DEI by job categories and life stages, few studies have specified what jobs are included in each category and stage. Therefore, current quantification results are blurry and hard to compare. As shown in

Table 1
The installed capacity and share of each renewable energy in 2011 and 2020 in China's power generation sector.
Source: National Electricity Industry Statistics Briefing 2011 [11]; The 12th five-year plan in the power industry [12].

Type of RNE	2011-Installed capacity (GW)	2020-Installed capacity (GW)	2011-Capacity share (%)	2020-Capacity share (%)
Hydro	232.98	360	22.4	19.2
Non-hydro	66.6	295	6.4	15.7
Nuclear	12.57	80	1.2	4.3
Wind	46.23	180	4.5	9.6
Biomass	5.59	10	0.5	0.5
Solar PV	2.22	25	0.2	1.3
Total	**299.6**	**655**	**28.8**	**34.9**

Table 2
Review of studies related to distributional employment impacts.
Source: Own elaboration from [5,6,13–19].

Year	Authors	Name of the study	Research objective/ geographical scope	Definition/method	Research content/key results related to distributional employment impacts
2012	Lambert and Silva [13]	The challenges of determining the employment effects of renewable energy	Renewables/ n.a.	No clear definition/review	Three job categories (technological development, installation/uninstallation, operation and maintenance) and job skills should be taken into account to make it clear how many jobs were created at each phase of the life cycle of the renewable energy project
2011	Tourkolias and Mirasgedis [14]	Quantification and monetization of employment benefits associated with renewable energy technologies in Greece	Renewables —Greece	No clear definition/I/O	Two phases (construction and operation) are considered respectively to estimate the employment benefits resulting from the development of different renewable technologies. A distributional I/O model is used, taking territorial factor (local/foreign) into account
2010	Sastresa et al. [6]	Local impact of renewables on employment: assessment methodology and case study	Renewables —Spain	Defined by territorial situation, technology, business structure, education supply and professional structure/Analytical	Three stages (technological development, installation/uninstallation, operation and maintenance) in the life cycle of each renewable technology are defined quite clearly. Distributional factors are used to analyze the employment impacts
2009	Wei et al. [5]	Putting renewables and energy efficiency to work: how many jobs can the clean energy industry generate in the US?	Power sector —US	No clear definition/Analytical	The study classified job roles into manufacturing, operation, and fuel extraction and processing, and captured the data from a series of researches. However, the distributional factor was only used as an intermediate variable to calculate overall data
2009	Waclawek et al. [15]	Michigan green jobs report 2009	Economic entity —Michigan	No clear definition/Analytical	Jobs features are considered. Jobs with high need of science, technology and engineering knowledge are most difficult to find suitable workers
2009	Blanco and Kjaer [18]	Direct employment in the wind energy sector: an EU study	Wind —EU	Defined by job category and gender/ Analytical	Besides suggesting a series of education measures to satisfy the huge demand on specialized workers including project manager, engineer and operating workers, this study also paid attention on gender, and found males make up 78% of the workforce in wind industry while the percentage is 55.7% in the overall EU labor market
2008	Moreno and Lopez [19]	The effect of renewable energy on employment. The case of Asturias (Spain)	Renewables —Spain	Defined by life stage, required skills, professional profiles and educational level/Analytical	The study analyzed the emergent professional profiles and required skills related to the new jobs generated in the installation, operation and maintenance of the different renewable energy systems
2004	Kenley et al.[16]	US job creation due to nuclear power resurgence in the United States	Nuclear —US	No clear definition/Analytical	The job roles in nuclear plants were classified into manufacturing, installation and operation

Table 3
Distributional employment impacts of different energy technologies per unit of power generation (defined by job roles).
Source: Own elaboration from [5,14,16,19,20]. CIM means “construction, installation and manufacturing”; O&M means “operation and maintenance”.

Energy technology	Source of numbers	Classification 1		Classification 2		
		CIM	O&M	Manufacturing	Installation	O&M
Biomass 1	Tourkolias and Mirasgedis [14]	25.7%	74.3%			
Biomass 2	Wei et al. [5]	10.2%	89.8%			
Biomass 3	Moreno and Lopez [19]	96.6%	3.7%			
Hydro 1	Tourkolias and Mirasgedis [14]	44.9%	55.1%			
Hydro 2	Wei et al. [5]	11.1%	88.9%			
Hydro 3	Moreno and Lopez [19]	93%	7%			
Solar PV 1	Tourkolias and Mirasgedis [14]	75.8%	24.2%			
Solar PV 2	Wei et al. [5]	69%	31%			
Solar PV 3	Moreno and Lopez [19]	92.8%	7.2%			
Solar PV 4	Renewable Energy Policy Project (REPP) [20]			72%	20.8%	7.2%
Wind 1	Tourkolias and Mirasgedis [14]	53.4%	46.6%			
Wind 2	Wei et al. [5]	50.8%	49.2%			
Wind 3	Moreno and Lopez [19]	98.5%	1.5%			
Wind 4	Renewable Energy Policy Project (REPP) [20]			65.9%	14.1%	20%
Nuclear 1	Kenley et al. [16]			31.6%	31.6%	36.8%
Nuclear 2	Wei et al. [5]	35.7%	64.3%			

Table 3, there are significant differences among the results of those studies, even among those using the same method of job classification. Indeed, the DEI will vary according to the location of the project, the particular technologies used, the scale of production and even the units of measurement; but the significant differences still warn us that there is a necessity to clarify the definition [5,19]

Table 4
Comparison of the policy scenario and the reference scenario.
Source: Installed capacity data of RNE in the policy scenario and Reference scenario are based on [12]; Utilization ours and generation cost data are adopted from Cai et al. [7].

Type of power generation technology	Installed capacity in 2011 (GW)	Policy scenario			Reference scenario		
		Installed capacity in 2020 (GW)	Utilization hours (h)	Generation cost (RMB/kW h)	Installed capacity in 2020 (GW)	Utilization hours (h)	Generation cost (RMB/kW h)
Coal-fired	/	0	4941	0.26	256.1	4941	0.26
Hydro	232.98	360	3450	0.34	232.98	3450	0.34
Nuclear	12.57	80	7292	0.49	12.57	7292	0.49
Wind	46.23	180	2100	1.03	46.23	2100	1.03
Biomass	5.59	10	6000	0.65	5.59	6000	0.65
Solar PV	2.22	25	1233	6.44	2.22	1233	6.44

and that there is danger in using job ratios from other studies or locations [1].

3. Methods

As addressed in the introduction section, it is believed that I/O models are more suitable for studying the DEI problem when there is sufficient supporting data. Therefore, in this study, an extended I/O model is established to study the DEI of RNE development through 2020 in China's power generation sector.

3.1. Definition of the distributional employment impacts in this study

The distribution of employment impacts can be defined by job roles, specialized levels, territorial/temporary natures, genders, etc. In this study based on I/O models, we define the DEI by specialized levels and genders in order to inform the policy makers about the possible mismatch with current personnel structure and the possible aggravating gender-inequality problem. Based on the data in the 6th national-scale demographic census [10], specialized levels in this study are classified into seven categories: unlettered, elementary school, middle school, high school, junior college, regular college and postgraduate.

3.2. Setting of scenarios

In order to research the DEI of RNE policies in power generation through 2020, we set up one policy scenario (referred to as “pol” in the following equations) and one reference scenario (referred to as “ref” in the following equations) for China's power generation industry. In the policy scenario, the installed capacity of each RNE is set based on the power development plan through 2020 [12]. As the role of reference scenario is to reflect the power generation regime without the RNE development policy, the reference scenario is therefore set under assumptions that (1) the installed capacity of RNE remains at the 2011 level, and (2) the increase of installed capacity of RNE in the policy scenario will be replaced by coal-fired units, while keeping the amount of electricity generated the same as in the policy scenario.

Why do we use coal-fired units (specifically 300 MW and above) to replace RNE in the reference scenario? As is well known, China's power generation sector has been dominated by coal-fired generating units for a long time. In 2011, coal-fired generation units accounted for 65.5% of total installed capacity in China [11]. Due to the advantages in generation cost, resource availability and level of technical maturity, building coal-fired units (300 MW and above) – remains the first choice for China to meet increasing electricity demands, when there is no driving force from RNE policy. Therefore, we believe using coal-fired units (300 MW and above) to replace RNE in the reference scenario reflects the most probable situation if China has no RNE development policy.

Detailed installed capacity and utilization hour for each scenario are displayed in Table 4. In order to highlight the impacts of installed capacity changes to the DEI, we assume the utilization hours of each power generation technology in both scenarios are the same. As we only focus on RNE in this study, the installed capacity of coal-fired units in the policy scenario for 2020 is set to be zero. The installed capacity of coal-fired units in the reference scenario is calculated by the following equation:

$$IC_{1,t,ref} = \sum_i \left[(IC_{i,t,pol} - IC_{i,t,ref}) \times \frac{h_i}{h_1} \right] \quad (i = 2, 3 \ldots 6; \quad t = 2020) \tag{1}$$

where i refers to various power generation technologies; $i=1, 2, 3, 4, 5, 6$ represents coal-fired, hydro, nuclear, wind, biomass, and solar PV generating unit, respectively; $IC_{i,t,ref}$ or $IC_{i,t,pol}$ is the volume of installed capacity of generation technology i at the end of year t in reference or policy scenario; h_i is the annual usage hours of technology i, so h_i/h_1 acts as a conversion factor from technology i to large coal-fired generation to keep the same amount of electricity generation between the policy scenario and the reference scenario.

3.3. Method of calculating the DEI of RNE policies in China's power sector

3.3.1. The I/O model and the splitting of power sector

China's I/O tables have been published every 5 years since 1987. In this study, the extended I/O model is built upon the Chinese 2007 input–output table (42 sectors × 42 sectors) [21], which is the latest official data available. As China's economy is still going through remarkable structural changes, it is nearly impossible to predict the interdependencies between different sectors in China's economy throughout 2020. Therefore, we made a very strict assumption in this study that these interdependent relationships between sectors will remain the same between 2007 and 2020. Apparently this is a compromise solution in the face of great prediction and uncertainty challenges. But the I/O analysis could still show us the trend of economic activity changes and employment changes brought by RNE development.

In this original table, the input–output relationship between the power sector and other sectors is clearly shown. However, to display the structural change within the power sector and to study the DEI brought by RNE's development, there is a further need to highlight the interdependencies of renewable energy – which is a part of the power sector – with other sectors in the economy. Therefore, we split the original integrated power sector into 9 subsectors according to various types of power generation technologies (hydro, wind, biomass, solar, small coal-fired, large coal-fired, natural gas, oil, and the others). The detailed splitting principles and processes can be found in Wang et al. [22]. In short, the

Table 5
The sectoral aggregation results and the CIC matrix in the IO model.

(a) Symbols for the aggregated sectors	
Aggregated sectors from original I/O table	Symbol
Agriculture, Forestry, Animal Husbandry and Fishery	A
Mining and Washing of Coal	B
Oil, Natural Gas and Nuclear Fuel Industry	C
Other Mining Industry	D
Consumption Goods Industry	E
Raw Material Industry	F
Manufacture of Machine	G
Production and Supply of Power, Gas and Water	H
Construction Industry	I
Tertiary Industry	J
(b) Symbols for the sub-sectors	
Sub-Sectors divided from Production and Supply of Power, Gas and Water	Symbol
Small Coal-fired	H1
Large Coal-fired	H2
Oil	H3
Gas	H4
Hydro	H5
Nuclear	H6
Wind	H7
Biomass	H8
Solar PV	H9
Production and Supply of Gas and Water	H10

original integrated power sector is split first horizontally according to each generation technology's fuel types, generation costs, generation volume, amount of investment and other technical characteristics. Then the split table is put back into the original I/O table, which forms a new 42×50 table. This table is finally smoothed by the modified RAS method [23] and becomes a new, balanced 42×50 table. To make the sectoral aggregation in this table comparable to the one in China's demographic census, we further sum up related sectors in the 42×50 table and finally get a 10×19 table. The sectoral aggregation results are shown in Table 5, together with the cumulative input coefficients (CIC) matrix.

3.3.2. The detailed equations to calculate DEI

The total employment impacts (EI) of RNEs can be expressed by the total number of jobs that would have been created in the policy scenario (ΔE_{pol}) minus the number of jobs that would have been created in the reference scenario (ΔE_{ref}).

$$EI = \Delta E_{pol} - \Delta E_{ref} \tag{2}$$

For each scenario, employment gains from 2007 to 2020 equals the product of incremental power generation (ΔGEN_i) and the elastic coefficient between employment and power generation ($GENCOEF_i$).

For example, in the policy scenario,

$$\Delta E_{pol} = \sum_i (\Delta GEN_{i,pol} \times GENCOEF_i) \quad (i = 1, 2, \ldots 6) \tag{3}$$

Obviously, the incremental power generation of technology i in the policy scenario equals the amount of incremental installed capacity ($\Delta IC_{i,pol}$) multiplied by the corresponding usage hours (h_i).

$$\Delta GEN_{i,pol} = \Delta IC_{i,pol} \times h_i \quad (i = 1, 2, \ldots 6) \tag{4}$$

$$\Delta IC_{i,pol} = IC_{i,t,pol} - IC_{i,s,pol} \quad (i = 1,\ 2,\ \ldots\ 6;\quad s = 2007,\ \ t = 2020) \tag{5}$$

The elastic coefficient between employment and power generation equals the product of the elastic coefficient between employment and monetary output value of technology i ($OVCOEF_i$), and the monetary output value per unit of power generated by technology i (OV_i/GEN_i). Following the assumptions made in Cai et al. [7], here we also assume that the generation cost of each power generation technology (C_i) is a constant parameter through time, and there is a fixed conversion factor (θ) between technology's generation cost and its monetary output value in the input–output table. Therefore, we have,

$$GENCOEF_i = OVCOEF_i \times \frac{OV_i}{GEN_i} = OVCOEF_i \times C_i \times \theta \quad (i = 1, 2, \ldots 6) \tag{6}$$

θ is calculated by total output of the power sector divided by total generation cost in 2011 and is at the value of 3.54 in this study.

Assuming for each sector m in the input–output model, there is a sector-specific fixed relationship γ_m between sectoral employment and sectoral output value, then,

$$OVCOEF_i = \sum_m (OV_{m,i} \times \gamma_m) \quad (m = 1, 2 \ldots 10;\ \ i = 1, 2, \ldots 6) \tag{7}$$

where $OV_{m,i}$ represents the output value of sector m brought by one unit of output value increase of technology i, which can be easily calculated through CIC matrix.

In order to calculate DEI, it is needed to consider the structure of employment on the base of EI. Multiplying γ_m by the proportion of labor category n in sector m ($p_{m,n}$), we can get a distributional relationship ($\gamma_{m,n}$) between each labor category and sectoral output value.

$$\gamma_{m,n} = \gamma_m \times p_{m,n} \qquad (m = 1, 2 \ldots 10;\quad n = 1, 2, \ldots 7 \text{ or } n = 8, 9) \tag{8}$$

where n refers to the type of labor in the labor market; n=1,2,…7, represents respectively unlettered, elementary school, middle school, high school, junior college, regular college and postgraduate, while n=8,9 refers male and female respectively; m refers to 10 sectors. See Table 6 for the detailed value of γ_m and $p_{m,n}$.

Finally, replacing γ_m in Eq. (7) with $\gamma_{m,n}$ and once again performing the calculation process of EI (from Eqs. (2)–(7)), we can easily get the DEI.

Obviously,

$$\mathrm{EI} = \sum_n \mathrm{DEI}_n \quad (n = 1, 2, \ldots 7;\ \text{or } n = 8, 9) \tag{9}$$

4. Results of DEI from RNE policies in China

4.1. Results of overall and distributional employment impacts of the RNE policies in China's power sector through 2020

Through Eqs. (1)–(9), the employment impacts of renewable and new energy in China are calculated and displayed in Table 7.

From the overall employment impacts perspective, it is found out that the renewable and new energy development policies will bring total employment gains to China. The new employment opportunities for the whole society from 2011 to 2020 could be as great as 7.16 million when comparing the policy scenario with the reference scenario. The main reasons for the employment gains are that (1) RNE has a higher generation cost than coal-fired units, resulting in larger impacts on other sectors through an input–output relationship; (2) the sectors that are promoted by RNE have higher labor intensities than those promoted by coal-fired units.

From the distributional employment impacts perspective, it is found that, when compared with the reference scenario, the new employment opportunities in the policy scenario focus on those with a middle school level of education. The proportion of employment opportunities at the education levels of unlettered, elementary school, middle school, high school, junior college, regular college and postgraduate is 1.2%, 12.4%, 44.2%, 23.0%, 11.4%, 7.0% and 0.7%, respectively. The educational categories

Table 6
The educational and gender structure of the 10 sectors in China in 2010.
Source: Tabulation on the 2010 population census of the People's Republic of China [10].

m	Name of the sector	γ_m (jobs/ 10000RMB)	$p_{m,n}$								
			Unlettered (%)	Elementary school (%)	Middle school (%)	High school (%)	Junior college (%)	Regular college (%)	Postgraduate (%)	Male (%)	Female (%)
1	Agriculture, Forestry, Animal Husbandry and Fishery	0.251	6.3	37.2	50.1	5.8	0.5	0.1	0.0	50.8	49.2
2	Mining and Washing of Coal	0.013	0.6	13.3	55.5	20.6	7.3	2.6	0.1	86.0	14.0
3	Oil, NaturalGas and Nuclear Fuel Industry	0.011	0.1	2.6	21.1	38.7	21.3	14.8	1.3	68.5	31.5
4	Other Mining Industry	0.010	1.0	17.5	53.0	19.7	6.1	2.4	0.2	81.2	18.8
5	Consumption Goods Industry	0.030	0.9	15.8	61.5	15.8	4.2	1.7	0.1	47.2	52.8
6	Raw Material Industry	0.012	0.9	14.3	53.4	21.3	7.1	2.9	0.2	67.3	32.7
7	Manufacture of Machine	0.019	0.4	9.1	50.8	25.1	9.0	5.0	0.5	63.2	36.8
8	Production and Supply of Power, Gas and Water	0.006	0.2	4.2	28.3	33.1	22.0	11.5	0.8	71.4	28.6
9	Construction Industry	0.021	1.1	19.9	60.5	12.5	3.9	2.0	0.1	85.6	14.4
10	Tertiary Industry	0.048	0.7	8.7	40.0	23.7	15.2	10.6	1.2	52.8	47.2

Table 7
The distributional indirect employment impacts caused by RNE policies in 2020.

(a) Employment distribution in terms of educational level

DEI (unit: thousand people)	Unlettered ($n=1$)	Elementary school ($n=2$)	Middle school ($n=3$)	High school ($n=4$)	Junior college ($n=5$)	Regular college ($n=6$)	Postgraduate ($n=7$)	Total
	89,326	886,354	3169,749	1648,381	816,232	504,349	50,248	7164,642
Percentage	1.2%	12.4%	44.2%	23.0%	11.4%	7.0%	0.7%	100%

(b) Employment distribution in terms of gender

	Male	Female	Total
DEI (unit: thousand employments)	4197,805	2966,837	7164,642
Percentage	58.6%	41.4%	100%

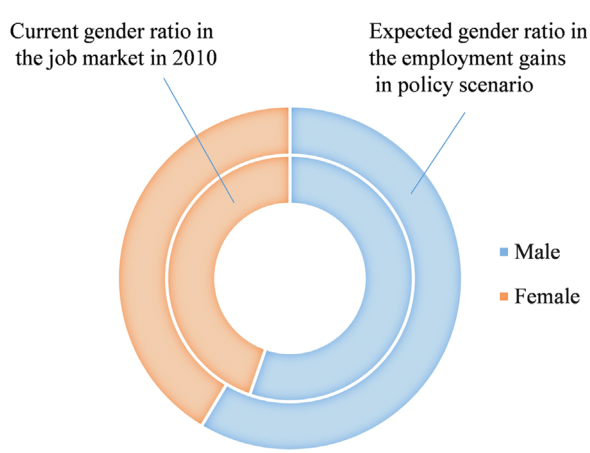


Fig. 1. The structure of DEI in terms of gender under the policy scenario and the comparison with the current gender structure. The outer ring reflects the expected male/female ratio in the employment gains under the policy scenario, while the inner ring reflects the current male/female ratio in the job market in 2010. Obviously, the policy scenario that focus on RNE development will exacerbate the gender imbalance problem.

beyond junior college account for 19.1% of the new employment opportunities. In terms of gender, most of the new employment opportunities are for males, and the proportion of male and female share is 58.6% and 41.4%, respectively.

4.2. The comparison between DEI and the current personnel structure

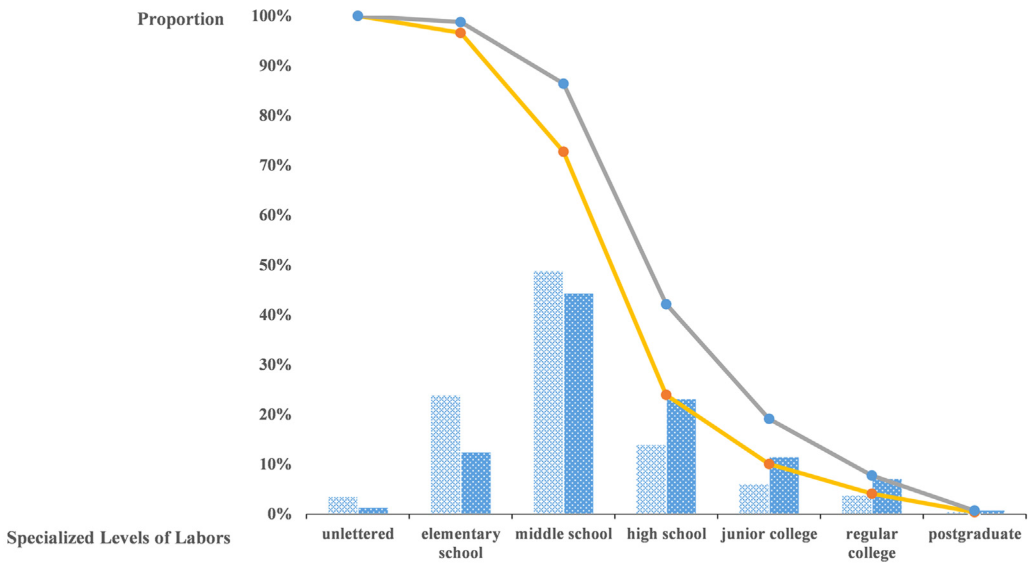
As mentioned in the introduction section, it is critical to study the DEI and to compare them with the current personnel structure (gender and educational), in order to avoid being blinded by the illusion of overall employment gains and to reveal the possibility of structural unemployment problem.

4.2.1. DEI vs. gender

From this study, it is estimated that through 2020, 58.6% of the employment gains will come from male workers, which is even larger than the share of male workers in China in 2010–55.3%, as shown in Fig. 1. Therefore it is proven that the development of RNE in China will add to the gender imbalance problem, which put women in a more disadvantageous position in China's job market.

From the CIC table, it is very easy to find the reasons. The RNE sector is most dependent on the inputs from the raw material industry and the manufacture of machine. In these two sectors, there exists long-term and severe gender isolation. The percentages of male workers in these two industries have reached as high as 67.3% and 63.2%, respectively. In fact, most of the 10 sectors in China's I/O table have a majority of male workers.

In China, the national and local government have committed to protecting the rights of female workers. Several laws, including the Constitution, Labor Law and Law on the Protection of Women's Rights and Interests, give a legal support to eliminate gender



Current Specialized Structure in China(2010)	3.4%	23.9%	48.8%	13.9%	6.0%	3.7%	0.4%	
Required Specialized Structure by RNE Scenario	1.2%	12.4%	44.2%	23.0%	11.4%	7.0%	0.7%	
Current Proportion abrove Specific Specialized Level in China(2010)	100.0%	98.8%	86.4%	42.1%	19.1%	7.7%	0.7%	
Required Proportion abrove Specific Specialized Level by RNE Scenario	100.0%	96.6%	72.7%	23.9%	10.1%	4.1%	0.4%	
Realizable Employment Index (assuming the total employment gains equal 100)	1.2	12.4	44.2	13.9	6.0	3.7	0.4	81.8(Total)

Fig. 2. The structure of DEI in terms of specialized levels under the policy scenario and the comparison with the current personnel structure. It clearly indicates that in the employment gains under the policy scenario, more specialized jobs will be needed compared to the current personnel structure, which might lead to a greater risk of structural unemployment.

discrimination in the labor market. However, the inequality of employment opportunity, career development and salary level is still a common phenomenon for female workers.

In this context, the worsening gender inequality problem brought by the development of RNE should raise serious concerns for China's policy makers, because more and more women will find it hard to get jobs. If the share of employed women could be raised, it will greatly increase the income for each family, improve the levels of family welfare, add to social stability and contribute to sustainable development.

4.2.2. DEI vs. personnel structure

Similar with the gender inequality problem, the mismatch between DEI and current personnel structure is also a critical problem, as it reveals that RNE needs more specialized jobs, which cannot be fulfilled without the professional education and the vocational training. Besides, adjustment of the personnel structure usually takes years or decades and is rarely achieved within short periods.

As shown in Fig. 2, it is found that the development of RNE in China will greatly increase demand for higher-quality labor and reduce demand for lower-quality labor. Of the total employment gains brought about by RNE from 2011 to 2020, the total share of labor with training from high school and the above levels reaches as high as 42.1%; the total share of labor from unlettered and elementary school is only 13.6%. However the respective shares in the personnel structure in 2010 were 24% and 26.3%. Obviously, if the personnel structure remains unchanged from 2010 to 2020, a portion of the projected employment gains will not be achieved due to the lack of high-level labor supplies; and another portion of low-level labor forces will fail to find jobs due to the shrinking market demand.

Fig. 2 has developed a new concept—the “realizable employment index”. It is calculated under the assumption that the total employment gains equal 100, and the actual personnel structure in 2010 will remain unchanged even with the development of RNE. In other words, in the overall employment gains, the actual personnel structure will remain the same as the 2010 level. Therefore the realizable employment index will be equal to 100 times of the smaller of the two values—the expected personnel structure in DEI of RNE from 2011 to 2020, or the actual personnel structure in 2010 in the economy. For example, although labors with junior college training is expected to account for 10.4% of the employment gains, the fact that its respective share in actual personnel structure is only 6.0% means the realizable employment index will equal $6.0\% \times 100$, i.e. 6.0. Generally speaking, due to the gap between those two values, the total realizable employment index is only 81.8, meaning only 81.8% of the total employment gains can be realized. The remaining 18.2% of the employment gains cannot be realized due to their mismatch with the actual personnel structure.

5. Conclusions and discussions

This study points out the necessity and the significance of studying the distributional employment impacts of renewable and new energy development. Based on a review of methodology and conclusions of existing literatures, it is the opinion of authors that, compared to analytical methods, I/O methods are more suitable for this field of study in terms of both preciseness and significance of the results.

Table A1
Value of sensitive parameters.

i	Power generation technology	$GENCOEF_{i,n}$, number of labor category n created or needed by each unit of power generation through technology i (jobs/GW h)									
		Unlettered ($n=1$)	Elementary school ($n=2$)	Middle school ($n=3$)	High school ($n=4$)	Junior college ($n=5$)	Regular college ($n=6$)	Postgraduate ($n=7$)	Male ($n=8$)	Female ($n=9$)	Overall
1	Large coal-fired	0.04	0.39	1.37	0.71	0.36	0.22	0.02	1.93	1.19	3.11
2	Hydro	0.05	0.50	1.80	0.94	0.48	0.28	0.03	2.47	1.62	4.09
3	Nuclear	0.06	0.61	2.22	1.30	0.67	0.42	0.04	3.22	2.09	5.32
4	Wind	0.18	1.82	6.47	3.21	1.58	0.96	0.10	8.46	5.86	14.32
5	Biomass	0.13	1.32	4.61	2.22	1.10	0.68	0.07	5.87	4.28	10.14
6	Solar PV	1.11	11.04	38.73	19.21	9.41	5.66	0.55	51.08	34.64	85.72

Table A2
The details of aggregated sectors in IO model.

m	Aggregated sectors	Original sectors
1	Agriculture, Forestry, Animal Husbandry and Fishery	Agriculture; Forestry; Animal Husbandry; Fishery
2	Mining and Washing of Coal	Mining and Washing of Coal
3	Oil, Natural Gas and Nuclear Fuel Industry	Extraction of Petroleum and Natural Gas; Manufacture of Refined Products; Processing of Nuclear Fuel
4	Other Mining Industry	Mining and Dressing of Ferrous Metals Ores; Mining and Dressing Non-ferrous Metals Ores; Mining and Dressing of Nonmetal Minerals Ores; Mining and Dressing of Other Ores
5	Consumption Goods Industry	Processing of Food from Agricultural Products; Manufacture of Food Manufacture of; Manufacture of Beverage; Manufacture of Tobacco; Manufacture of Textile; Manufacture of Textile Wearing Apparel, Footwear and Caps; Manufacture of Leather, Fur, Feather and Its Products; Processing of Timbers, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products; Manufacture of Furniture; Manufacture of Paper and Paper Products; Printing, Reproduction of Recording Media; Manufacture of Articles for Culture, Education, and Sport Activities; Manufacture of Fertilizer; Manufacture of Pesticide; manufacture of Paint, ink, pigment and similar products; Consumption Goods Industry Manufacture of Medicines; Manufacture of Artwork, Other Manufacture; Recycling and Processing of Waste Resource and Material
6	Raw Material Industry	Coking; Manufacture of Basic Raw Chemical Materials; Manufacture of Synthetic Materials; Manufacture of Chemical Fibers; Manufacture of Rubber; Manufacture of Plastics; Manufacture of Non-metallic Mineral Products; Smelting and Pressing of Ferrous Metals; Smelting and Pressing of Non-ferrous Metals
7	Manufacture of Machine	Manufacture of Special Chemical Products; Manufacture of Household Chemical Products; Manufacture of Metal Products; Manufacture of General Purpose Machinery; Manufacture of Special Purpose Machinery; Manufacture of Transport Equipment; Manufacture of Electrical Machinery and Equipment; Manufacture of Communication Equipment, Computer and Other Electronic Equipment; Manufacture of Measuring Instrument and Machinery for Cultural Activity and Office Work
8	Production and Supply of Power, Gas and Water	Production and Supply of Electricity; Production and Supply of Gas; Production and Supply of Water
9	Construction Industry	Construction
10	Tertiary Industry	Transportation, Warehousing and Postal service; Information Transmission, Computer Services and Software; Wholesale and Retail Trade; Hotels and Catering Services; Financial Industry; Real Estate; Leasing and Business Services; Scientific Research, Technological Services and Geological Prospecting; Management of Water Conservancy Environment and Public Facilities; Resident Services and Other Services; Education; Health, Social Security and Social Welfare; Culture, Sports and Entertainment; Public Management and Social Organization; International Organizations

An extended I/O model was built up to study RNE's distributional employment impacts on gender and personnel structure. The case study in China affirmed the earlier doubts that the development of RNE will indeed aggravate the gender inequality problem and add to the level of mismatch between the structure of labor demand and supply. More labor with high school and above levels of education will be needed than can be supplied; yet labor from unlettered and elementary school background will face a more difficult job market. The quantitative analysis implies that, due to the "mismatch" problem, only 81.8% of the estimated 7.16 million employment gains brought by the development of RNE from 2011 to 2020 can be realized. The study of China can alert other countries to be less-optimistic about RNE's employment impacts. RNE is a comparatively new sector for most of the countries in the world. Therefore it will bring significant changes to the current industrial structure, to the demand side of the labor market and to the management objectives for policy makers. If those changes can be addressed in a timely and precise manner, they could become opportunities; if not, they could become significant challenges.

In fact, there are many policies that, if implemented as soon as possible, could improve the matching between the distributional employment impacts and the current labor market. For the gender inequality problem, there is a need to break the traditional perception of gender as it relates to certain jobs, to break down the barriers from social attitudes, and to provide suitable training, equal treatment and promotion opportunities for women. Meanwhile, well-designed social protecting system and validly-implemented laws related to eliminating gender discrimination are the basic measures to solve this problem. For the transformation of current personnel system, the spirit of planning ahead is also urgently needed, because the demand-over-supply problem has been widely observed along with the rapid development of RNE. For universities and vocational training agencies, it is very important to set up majors related to research and development, manufacturing, installation, and operation and management

aspects of the RNE. They could also launch initiatives to provide training to employees in related sectors, in order to reduce the difficulties and time needed to change jobs in the RNE sector. For the government, it is crucial to provide supporting policies for training domestic human resources and for introducing high-end talent from abroad. They should also support the establishment of corporate R&D centers and post-doctoral research stations, to help shorten the personnel training cycle. It is also important for the government to reduce the illiteracy rate and to enhance the popularity of compulsory education. All the above measures can ease the concerns from this distributional employment impacts study, add to the positive impacts of RNE's development, speed up the development of RNE and further contribute to the formation of a low-carbon society.

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Appendix

See Table A.1 and A.2.

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